Determining the Characteristics and Mechanisms for Biological Clutter and Environmental Reverberation and Their Impact on Long Range Sonar Performance in Range-Dependent Fluctuating Ocean Waveguides

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LONG-TERM GOALS AND OBJECTIVES

Determine the temporal and spatial characteristics, and physical mechanisms for clutter and environmental reverberation in instantaneous-wide-area underwater acoustic imaging and surveillance systems. This understanding is used to develop operational and signal processing techniques to distinguish clutter from scattered returns due to man-man targets, and to determine the limits placed by environmental reverberation on target detection. In the second area, the statistical properties of broadband acoustic signals transmitted and scattered in range-dependent ocean waveguides is examined. This knowledge is then used to determine the extent to which environmental variabilities limit our ability to perform target localization and parameter estimation through beamforming and matched-filtering broadband data from imaging systems in fluctuating and dispersive ocean waveguides.

APPROACH

The research effort involves developing and enhancing physics-based theoretical models for scattering from groups of fish, marine mammals and other biological organisms, multi-static scattering from extended targets, and environmental reverberation in *range-dependent* ocean waveguides. The data from the ONR-sponsored experiments in the Gulf of Maine in 2006 and on the New Jersey Strataform in 2003 measured with instantaneous-wide-area ocean acoustic waveguide remote sensing systems are processed and analyzed.

WORK COMPLETED AND RESULTS

1. Effect of signal bandwidth on saturated transmission scintillation statistics in a shallow water waveguide

The scintillation statistics of broadband acoustic signals in the 300 to 1200 Hz frequency range transmitted through a shallow water waveguide are examined using data from the Gulf of Maine 2006 Experiment and a stochastic propagation model that takes into account the randomizing effects of internal waves. Broadband linear frequency modulated (LFM) signals transmitted through Georges Basin, approximately 200 m deep, with source-receiver separations ranging from 5 to 20 km have been

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processed to estimate the signal standard deviations and coherence bandwidths as a function of center frequency. The stochastic propagation model was calibrated with data from the experiment and used to study the saturated broadband scintillation statistics as a function of range.

Our analysis indicates that a short duration monotonic signal attains a roughly 5.6 dB standard deviation at saturation that stays consistent with increasing range. The broadband signal on the other hand was found to have a standard deviation of less than 5.6 dB upon saturation and it further decreases with increasing range. Although each individual frequency component is saturated, decorrelation across the bandwidth of a broadband signal increases the number of independent fluctuations, or coherence cells, thereby reducing the variation in total signal intensity. Coherence bandwidths were found to be larger for higher frequency signals, which are associated with larger standard deviations. The approach to saturation, characterized by a unity scintillation index was also examined. Our analysis indicate that a low frequency monotonic signal has a scintillation index that approaches 1 from below while for a high frequency monotonic signal, the scintillation index approaches 1 from above. The range dependence of signal statistics and the approach to saturation are consistent with measurements of electromagnetic optical laser beam and radar wave propagation statistics in the atmosphere.

2. Long Range Passive Source Localization and Tracking with Horizontal Towed Array Measurements

We are investigating several different approaches for instantaneously localizing and tracking broadband intermittent sound sources passively over long ranges with measurements received on a horizontal towed array. The methods include the synthetic aperture technique (SAT), the array invariant and the waveguide invariant methods. With a high-resolution towed horizontal line-array, accurate bearing estimates of a sound source can be obtained by conventional plane-wave beamforming. The SAT maps the sequential bearing estimates of a radiating sound source and the corresponding position and velocity of the receiver array measured by the onboard GPS receiver onto a Cartesian grid to estimate the source horizontal trajectory. A linear or non-linear least square fit is performed to reduce the variance in the bearing measurements, which lead to a minimum squared error solution. The method is applied to localize a vertical source array deployed in the Gulf of Maine Experiment in 2006 that was either moored or drifting with the current. The source transmitted low-frequency short duration broadband signals at constant intermittent time intervals, and was received on a towed horizontal receiving array. The source location and trajectory estimated using SAT show consistently good match with the true source position in both the moored and drift modes. This was true for the wide range of source-receiver geometries and even for large variations in the velocity and heading of the towed receiver array, which may lead to a diverged result using other bearing-only target motion tracking methods. Our future plan is to compare the source localization and motion tracking results inferred using SAT to those made using other passive source localization methods applicable for single towed receiving array, such as the array invariant and the waveguide invariant methods, and a standard bearing-only target motion tracking algorithm implemented using the extended Kalman filter.

3. Development of a theoretical model for multiple scattering, attenuation and dispersion from a group of random scatterers in an ocean waveguide.

A numerical Monte-Carlo model has been developed to examine multiple scattering, dispersion and attenuation from a group of random scatterers from long ranges in an multi-modal ocean waveguide The model has been applied to simulate the 2006 Gulf of Maine experiment to study scattering from

Atlantic herring populations and determine population density imaging with a waveguide remote sensing system. Analysis with the model indicate that the areal population of fish groups can be estimated from their incoherently averaged broadband matched filtered scattered intensities measured using a waveguide remote sensing system with over 90% accurary. Furthermore, the scattering from large fish groups typically imaged using a waveguide remote sensing system is dominated by the incoherent intensity so that resonant shift effects are negligible or absent and the total scattered intensity is independent of the exact 3D position of the scatterers and only depend on their volumetric density within each resolution footprint of the imaging system as shown in Figs. 1(b) and 2(a). For small fish groups, on the order of the acoustic wavelength or smaller, resonant shifts can occur and the total scattered intensity depends on the exact 3D spatial location of each scatterer as shown in Fig. 2(b).

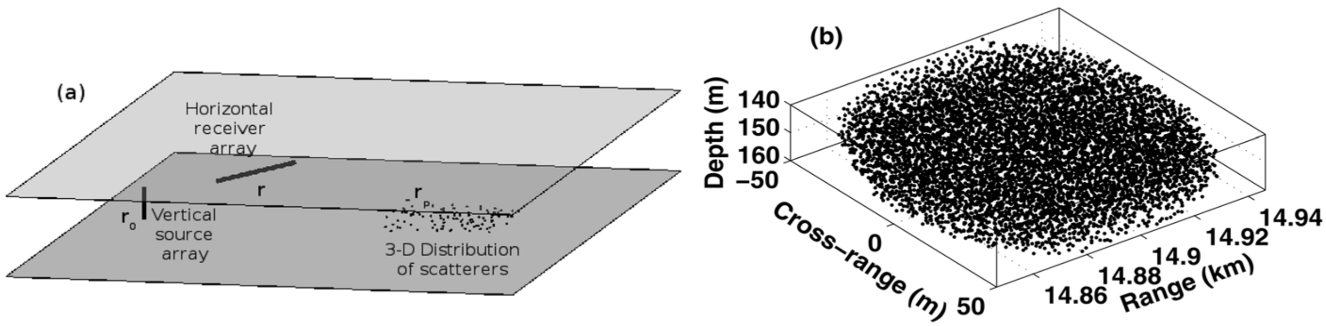

Figure 1: (a) Geometry of the bistatic acoustic imaging system in an ocean waveguide. (b) 3D spatial configuration of a large herring group containing 7831 individuals. Figure taken from Ref. 1

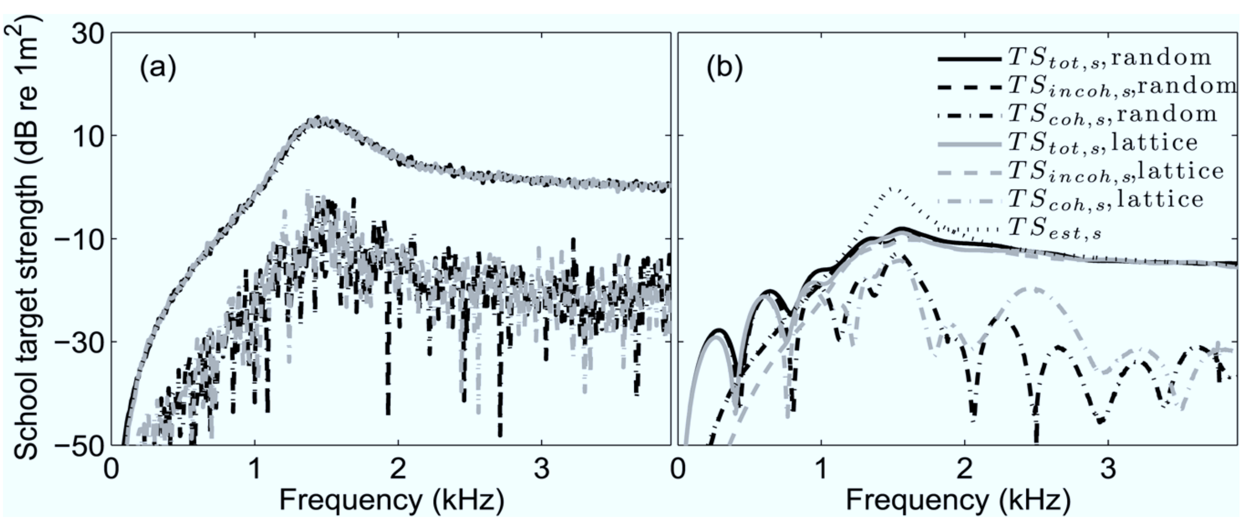

Figure 2: Effect of the 3D spatial configuration on the time harmonic fully scattered field moments, including multiple scattering, as a function of frequency for a monostatic directpath imaging system examined for (a) a large herring group containing 7831 individuals and [shown in Fig. 1(b)] and (b) a small herring group containing 240 individuals. The coherent, incoherent, total and estimated school target strength spectra are compared as a function of the fish group spatial configuration. Figure taken from Ref. 1.

The widely-used theoretical model for studying resonance scattering from fish swimbladder has been calibrated with data from our ONR-sponsored 2003 New Jersey shelf and 2006 Gulf of Maine experiments for the Atlantic herring fish species. We are now applying the model to study scattering from groundfish, such as cod and hake that inhabit the waters of the Gulf of Maine. The groundfish are much bigger fish with mean lengths typically exceeding 50 cm, compared to 25 cm for herring. The groundfish resonate at frequencies lower than 1 kHz and are an important source of bioclutter at these low frequencies. The fish resonant scattering model coupled to waveguide scattering models have been applied to simulate the scattered levels from a group of groundfish received by a long range waveguide remote sensing system and compared to background reverberation. The models will be used to determine whether bio-clutter from groundfish is significant at frequencies below 1 kHz for a waveguide remote sensing system. Despite their current low abundances, the groundfish have higher TS at resonance compared to other keystone fish species such as herring that may make their overall scattered levels non-negligible.

IMPACT/APPLICATIONS

We have shown that resonant scattering shifts from fish groups can only occur for fish groups smaller than the acoustic wavelength, thereby making bio-clutter more predictable in long range waveguide sensing systems that are typically dominated by scattering from larger fish groups.

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